# War of attrition in the Arctic offshore: Technology spillovers and risky investments in oil and gas extraction

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# Preface

A big part of my motivation to start studying environmental economics came from wanting to write a master's thesis about the oil and gas extraction in the Arctic. I always knew how interesting it would be to study the dynamics of this region, but I did not realise how challenging it would get. Going from learning about the actual situation in the Arctic, to searching for applicable theories, and to finally developing my own, has been a great learning process.

I would like to thank my supervisor Bård Harstad who has been of great help throughout the theory development, and who I have learned a lot from. I would also like to thank Daniel Spiro for challenging me to choose an alternative starting point for the theory.

I am very lucky to have a slightly smarter older brother who has been kind enough to help me in testing and fool proofing of theories, all the way from Tokyo. Thank you Jarkko.

The Fridtjof Nansen Institute granted me a scholarship for the duration of the writing process, which not only allowed me to borrow an office at Polhødga, but also gave me the chance to meet some inspiring people. That I am grateful for.

Finally, a thank you to Kim who kept assuring me that it is going to work out in the end. Once again, you were right.

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# Abstract

The Arctic offshore is an extremely difficult area for petroleum industry activity due to distance from infrastructure, harsh climate, unpredictable weather conditions, and vulnerability of the eco system. However, it is also a region with great oil and gas potential. A model developed in this paper studies the oil and gas extraction strategies of two countries, Norway and Russia, wanting to enter the Arctic offshore. The strategies are analysed through using a war of attrition game, where both countries play a mixed strategy, i.e. they enter the Arctic offshore in every period with some probability.

First, the model studies the effect of two sources of inertia, namely the second-mover advantage, arising due to a technology spillover, and the irreversibility of investment. Both of these factors are found to hinder the entry to the Arctic offshore.

In addition, the model is extended to include a possibility of an oil spill occurring in the Arctic offshore and a periodical reduction in the expected investment payoff. The possibility of an oil spill is found to reduce the countries willingness to enter the Arctic, whereas the periodical reduction in expected investment payoff is found to increase the willingness of the countries to enter the Arctic, as the sooner the extraction starts, the larger the expected investment payoffs will be, ceteris paribus.

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# 1 Introduction and Summary

The Arctic offshore is an extremely difficult area for petroleum industry activity due to distance from infrastructure, harsh climate, unpredictable weather conditions, and vulnerability of the eco system. However, according to an estimation made by the United States Geological Survey (USGS) (2008), the polar region contains up to 22 per cent of world's undiscovered conventional oil and gas resources. This survey includes both onshore and offshore deposits, of which 84 per cent are located offshore (Claes and Moe, 2014, p. 103). The potential that lies beneath the Arctic ice makes the region an attractive region for resource extraction. However, oil and gas extraction in the Arctic can also be costly as it, for example, requires technology that can safely operate in the rough conditions and the workers can claim higher wages due to the remoteness of the extraction sites. This study analyses the Arctic extraction strategies of two countries, Norway and Russia, and attempts to determine the factors that increase and decrease their willingness to enter the Arctic offshore.

The Arctic offshore is not only an important source of resource income for the Arctic countries, but it also plays a role in the development of the global energy market. The Arctic deposits are considered as perhaps the last large-scale conventional finding outside the *Organisation of the Petroleum Exporting Countries* (OPEC), thus being of great interest also to the countries importing oil and gas (Lindholt and Glomsrød, 2011, p. 4). However, according to Moe (2014, p. 247) the role of the Arctic as a source of oil may have declined due to the increase in unconventional oil production in the United States (US), for example.

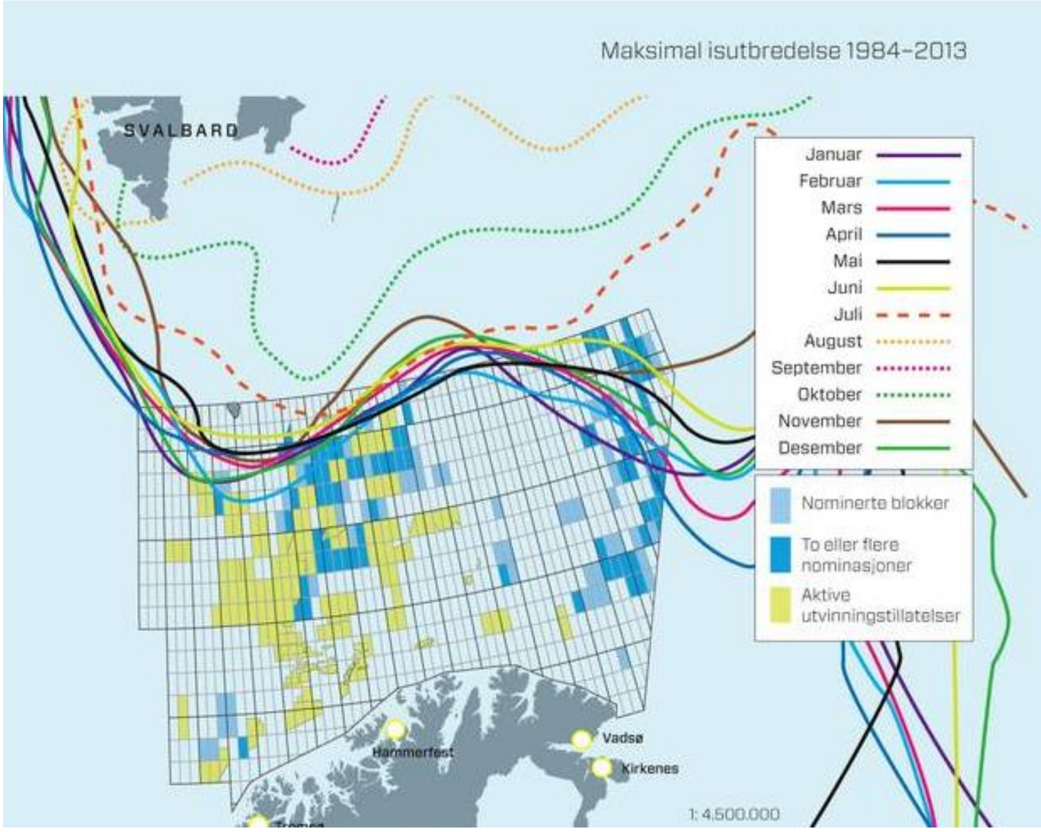
A paper published in March 2015 by the World Bank, *The Great Plunge in Oil Prices: Causes Consequences and Policy Responses*, defines the increase in unconventional production, OPEC's decision not to cut production, and low global demand for oil as the main reasons for the drop in oil prices in the second half of 2014 (Baffes et al., 2015, p.4). The low oil prices have continued into 2015. This price drop has raised speculation regarding the profitability of drilling the more expensive wells, such as those in the Arctic. The International Energy Agency (IEA) has estimated that the global oil price will stabilize at around 60 USD/bbl for the next few years (RT, 2015).

This paper defines the Arctic as the area above the Arctic Circle, i.e. 66° 32" North, and looks especially into those regions where sea ice can be encountered on a yearly basis. This is because the model I have developed studies the role of appropriate extraction technology as a determining factor in being able to access the most demanding regions of the Arctic, for example, those off the coast of Russia where the sea is covered in ice most of the year. As mentioned above, the model uses the Norwegian and the Russian extraction strategies as case studies in order to analyse the dynamics between countries with heterogeneous cost levels looking to extract oil and gas in the offshore Arctic.

In Norway, the government has declared a no-drilling zone 50 kilometers from the edge of the ice (Oil, - and Energy Department, 2014)[1]. This zone is one of the highly debated issues around the Arctic extraction plans in Norway. The reason for this is that the environment, - and climate minister Tine Sundtoft suggested in the beginning of 2015 to update the definition of the edge of the ice to be located further north allowing for the oil, - and energy minister Tord Lien to include all the planned Arctic fields in the 23rd licensing round (Schjetne, 2015). This created unease amongst environmental organisations, some political parties and citizens. For example, the leader of the Norwegian World Wildlife Foundation (WWF), Nina Jensen, claimed that Sundtoft used expired data regarding the movements of the Arctic ice, ignoring the current data and suggestions by the Norwegian Polar Institute (WWF Norway, 2015). Thus, the definition of areas with current development potential is unclear and debated in the Norwegian Barents Sea. The disputed region and the movement of the ice is illustrated in Fig 1. below. I am assuming that the Russian government will allow for extraction to take place anywhere within its continental shelf, defined by the United Nations (UN) as seabed and subsoil of submarine areas up to 200 nautical miles off the coastline of Russia (United Nations, 2012), as nothing indicates otherwise.

[1] 15 December until 15 June. http://www.norskoljeoggass.no/Global/Beredskapsforum%202015/2%20Utfordringer%20beredskap%20i%20nord.pdf

Fig. 1. Suggested blocks and the movement of the ice edge over 12 months




In Norwegian: Maximum ice spread 1984-2013 (*Maksimal isutbredelse 1984-2013*). The colour-coding stands for: Light blue: nominated blocks, dark blue: two or more nominations, yellow: active exploration permits. The map shows the ice movements throughout a 12 months' period. The summary is based on meteorological data from the last 30 years. A share of the blocks suggested by the Oil- and energy department lies within this zone parts of the year (Magnussen, K. /TU, 2015).

## 1.1 Technology requirements for the rough conditions

The Arctic countries, the United States, Norway, Russia, Greenland (Denmark), Canada, are to some extent interested in increasing their industrial activity in the world's northernmost region. Due to the numerous challenges in the harsh area, great measures need to be taken before the resources can be responsibly extracted.

Due to the demanding conditions, the technology used for oil and gas extraction has to be able to tackle factors such as extremely cold temperatures, icepack damage, and long distances to supporting infrastructure (Claes and Moe, 2014, p.105). In addition, the response and rescue technology has to be functional in the same conditions, and potentially in complete darkness

(Arctic Response Technology, 2012). The effects that climate change has on the offshore Arctic are largely debated and the region is of interest to environmental organisations, governments and industry representatives due to its high environmental value and resource income potential. Even though the ice cover is reducing, the pace of reduction and its consequences are unclear (Bhatt et al., 2014, p. 58; Lindsay and Schweiger, 2015, p. 273; Zygmuntowska et al., 2014, p. 711).

The shrinking ice increases accessibility of infrastructure and transportation to the area. However, the changing conditions in the Arctic may also result in more frequent storms and increased water movement, which can create great problems for the industry (Wassnik and van der List, 2014, p. 3). Thus, due to these conditions in the Arctic offshore, the technological development plays a great role in determining who will be able to initiate extraction and when it will happen. As of today, none of the Arctic countries, or companies exploring within their jurisdiction, have proven to have the appropriate technology. However, it is assumed in this paper that some countries have developed their technologies further than others have, and are therefore more likely to be able to enter the hostile waters first.

Norway is known for its effective and secure extraction technology, and has justified its oil and gas extraction activity by claiming that Norway should set the standard for Arctic extraction, in relation to the environmental concerns in the area, especially to Russia (Jensen, L. K., 2007, p. 249). Even though these claims about Norway's so-called environmentally friendly oil and gas extraction may be debatable, the signals from the industry are indicating that Norwegian Statoil has developed its Arctic extraction technology quite far in comparison to for example the Russian companies, Rosneft and Gazprom. As an example, the Norwegian company Statoil in cooperation with the Italian oil company ENI have finalised the construction of the Goliat rig, which arrived in Hammerfest in April 2015, and is expected to continue to the Arctic offshore, to the Goliat field, during the summer 2015. All this while Russia is struggling to find ways re-open the Universitetskaya-1 field which it was forced to give up on as the project partner Exxon, had to pull out of the development due to the sanctions by Western countries against Russia.

The technological innovations that allow companies to extract oil and gas in the Arctic, can spill over to other companies and regions once the development of technology has begun. In most offshore oil and gas projects, there are various companies involved. These companies share information and develop technology together.

The technological innovations are then assumed to spread from one project to another through for example cooperation, labour movement, industry expansion, industry communication and media. In this paper the effect is modeled through a relationship of two countries, Norway and Russia, which in reality may include various companies operating within their jurisdiction. Using countries in the model, rather than individual firms, simplifies the model. However, the model does not suffer from this simplification as the technology spillover-effect can be assumed to be identical from a single company to another, and the companies are assumed to face more or less the same cost-benefit considerations as the countries that give out exploration rights, and subsidise and tax the industry. The countries, Norway and Russia, were chosen due to the assumption of entry cost heterogeneity between them, and due to the assumption that Russia most likely will not be able to proceed to the offshore Arctic without technological assistance from the Western countries, such as Norway (Claes and Moe, 2014, p.111). However, the possibility of Russia entering first cannot be completely excluded as the sanctions may be relieved. Thus, the model considers the option that Russia enters the Arctic offshore before Norway does[2].

The model I have developed in this paper, analyses the probabilities with which these countries will enter the Arctic offshore, using a game theoretic approach. Currently, both of the countries have some activity in the Arctic offshore; Norway in the form of Snøhvit (Snow White), the natural gas field (Henderson and Loe, 2014, p. 46), and Russia in the form of Prirazlomnoye, an oil field in the Pechora Sea (Henderson and Loe, 2014, p.27). The future Arctic ventures will, according to the model, depend on such factors as the opportunity cost of alternative investment options in the future and cost reductions due to a potential technology spillover from the other country. In addition, two extensions are made; firstly a situation where both countries face some probability of an oil spill and secondly, a situation where the resource income, i.e. the investment payoff is reducing in every period due to high risk of reduction in fossil fuel demand at some point in the future.

[2] As the model aims at illustrating the effect of technology spillover on entry costs to the Arctic offshore, it is assumed that a technology spillover from Norway to Russia could allow Russia to initiate oil and gas extraction in the Arctic offshore, even without direct cooperation.

## 1.2 The technology investments as an indicator of industry strategy

The oil and gas industries are extremely volatile as they can experience unforeseen price fluctuations. The global oil price has been steadily rising in the last decade, thanks to high demand (Claes and Moe, 2014, p.97). In the summer of 2014, the market started falling and once the year ticket over to 2015, the oil price had more than halved from the highest point of circa 115 USD / bbl[3] to around 50 USD/bbl. In the end of February 2015, the International Energy Agency (IEA) estimated that the oil prices would stay at around 60 USD/bbl for the next few years (Farrell, 2015). In the end of the same month, OPEC announced that it is satisfied with a 60 USD/bbl price and refused to make immediate cuts in petroleum production in order to bring the prices up.

Following the price crash, speculations about the profitability of ongoing and future petroleum projects increased. According to a report by Rystad Energy (2013), the most expensive deposits are postponed or removed from project portfolios in times of low oil prices. Arctic oil drilling, being extremely demanding and expensive, has the risk of ending up in the category of unprofitable projects. The IEA (2008) estimates that the production cost per barrel in the Arctic ranges between 40 USD and 100 USD, whereas in the Middle East the production cost per barrel can be as low as five USD per barrel. However, the Norwegian owned Statoil quickly after letting its exploration permits in Greenland expire, came out with a statement saying that current low oil prices merely slow down the Arctic projects, but will not stop them (Reuters, 2015). Oil and gas companies are known to look several years ahead when planning projects, rather than focusing on the current market situation, thus analysing only the effect of oil price on Arctic development is not sufficient (Lewis, 2015).

Even though the fallen prices may have created uncertainty in the market and slowed down the development of the Arctic deposits, the investments in Arctic technology seem to continue, as nothing else has been signaled by the Arctic countries. Investing in exploration and extraction technology is a long -term commitment, since the investments may not create returns until years or possibly decades after discovering a deposit. Especially in the Arctic, where the conditions are relative difficult, commencing production may take longer than

[3] bbl stands for barrel

expected. In this paper, current technology investments are thus assumed to indicate how the industry predicts that the market will develop.

Countries, and companies working within their boundaries, are assumed to keep investing in oil and gas extraction technology as long as the expected net present value of extraction is positive, i.e. there is enough faith in market recovery and no great risks, other than some price fluctuation, are to be expected. Of course, the petroleum companies' ability to invest in new projects is not always in correlation with the willingness to invest. Therefore, the effect from reduced cash flow may be that some more expensive projects are postponed, as mentioned above, but not necessarily completely re-evaluated or cancelled (Taraldsen, 2015).

Signaling is also an important factor in oil price development. The oil industry may send over-confident signals to the market in order to boost investments, or at least avoid divestments. Especially in the last few years, when the climate change has become a more and more prominent topic in politics and the media of the Western world, it has made it challenging for the fossil fuel industry to find their footing in the future energy mix. Therefore, the unpredictable nature of the Arctic offshore oil and gas production does not only come from the costs related to technology requirements and the uncertainty around the size of the findings, but also from the threat of Arctic oil becoming a stranded asset. The stranded asset threat is studied in more detail below.

## 1.3 The risk of fossil fuels becoming stranded assets

The stranded assets risk is taken into consideration in the model developed in this paper through using a parameter $\theta$, which measures the countries' private evaluation of the opportunity cost of alternative investments in the future. The opportunity cost for these alternative investment options, such as for example renewable energy, may increase if the country finds the threat of stranded assets realistic in relation to Arctic oil and gas (Parkinson, 2015). In an extension of the model, where the possibility of the investment payoff, $X$, reducing in every period, the stranded assets risk is also considered as one possible factor for this to be happening.

A study made by the Stranded Assets Programme at the University of Oxford's Smith School of Enterprise and the Environment (Ansar, Caldecott, and Tilbury., 2013, p. 2) defines the risk factors that can lead to stranded assets, as follows:

- Environmental challenges
- Emerging fossil fuel substitutes
- New government regulations
- Renewable energy sources' decreasing prices making them increasingly competitive
- Evolving social norms and consumer behaviour
- Litigation and changing statutory interpretations

This study, financed by the WWF- United Kingdom (UK), examines the effects of divestment programs on fossil fuel assets. The study investigates a divestment campaign in the 1980s in South Africa, which put pressure on the South African government to end apartheid (Ansar, Caldecott, and Tilbury, 2013, p. 9).

The study concludes that divestments will most likely have little effect on the petroleum market, due to its already volatile characteristic. However, the main goal of fossil fuel divestment campaigns is to set new ethical and moral standards to investors, rather than attempting to financially corrupt the fossil fuel producers (Carrington, 2015).

The Carbon Tracker Initiative[4] also looks at the carbon emissions problem from the economic point of view, i.e. how the fossil fuel assets can become stranded assets as the shift to a low-carbon economy becomes reality. The Carbon Tracker Initiative's report by Leaton (2014), *Unburnable Carbon – Are the world's financial markets carrying a carbon bubble?* studies the threat of stranded asset and analyses whether the 'current financial markets could too heavily rely on fossil fuel assets'.

The carbon bubble, i.e. the difference between the fossil fuel production restrictions under global carbon budget for the two-degree goal for 2000-2050[5] and the current production

[4] See: http://www.carbontracker.org/
[5] See: http://www.un.org/en/globalissues/climatechange/

potential, creates an additional risk to producers and investors in the fossil fuel market. The report summarizes the current situation as follows:

*‘Research by the Potsdam Institute calculates that to reduce the chance of exceeding 2°C warming to 20%, the global carbon budget for 2000-2050 is 886 GtCO2. Minus emissions from the first decade of this century, this leaves a budget of 565 Gt CO2 for the remaining 40 years to 2050. …The total carbon potential of the Earth’s known fossil fuel reserves comes to 2795 GtCO2. 65% of this is from coal, with oil providing 22% and gas 13%. This means that governments and global markets are currently treating as assets, reserves equivalent to nearly 5 times the carbon budget for the next 40 years. The investment consequences of using only 20% of these reserves have not yet been assessed’.*

(Leaton, 2014, p.6)

Thus, the message is that only a small share of the fossil fuel deposits that the financial markets are currently considering as positive assets, will be developed if the carbon budget for the two-degree goal is to hold.

The stranded assets threat may thus become a reality if the countries with fossil fuel reserves commit to the UN’s two-degree goal or take their previous commitment seriously. In addition, if the global demand for fossil fuels reduces, the fossil fuel producing countries will be forced to cut production, thus potentially being unable to gain returns from investments. According to the publication by McGlade and Ekins (2014, p. 111), the Arctic oil and gas deposits should remain completely undeveloped in order to be able to reach the two-degree goal in a cost-effective way.

The UN is publically supporting the fossil divestment campaigns, according to a statement made by Nick Nuttall, a representative for the UN Framework convention on climate change (UNFCCC), on *the Guardian* (Carrington, 2015). This is because divesting from fossil fuels is ‘aligned with the UN’s goals of reduced climate gases’ and, more precisely, with the aim of creating a binding agreement at the UN’s Climate Conference in Paris in December 2015. It is likely, that the impact that stranded assets threat has on Norway’s, and perhaps also on Russia’s, Arctic investments becomes clearer after the Climate Conference, as the extent and details of the global climate agreement are revealed.

# 2 Literature review

The strategies for resource extraction in the Arctic waters have not been studied through a game theoretic approach to a great extent, especially in relation to the oil and gas resources. This paper analyses how the technology costs postpone entry to the Arctic offshore through applying a war of attrition game. A paper by Dosi and Moretto (2010), studies the sources of inertia in the development of environmental innovations. This study is applied to the Arctic, however in a simplified form, with some appropriate extensions. The theory application is supported by various papers and news articles describing the past, current, and future situation in the Arctic (Claes and Moe, 2014; Henderson and Loe, 2014; Jensen, 2007; McGlade and Ekins, 2014; Moe, 2014).

## 2.1 Many challenges and great resource potential

The paper by Henderson and Loe (2014) analyses the potential of Arctic oil and gas development in the next 20-30 years. The publication divides the Arctic into regions according to country sovereignty, thus analysing the Arctic prospects for the United States (US), Greenland, Canada, Russia, and Norway.

According to the publication, the Russian Arctic region is the largest one, covering over half of the total coastline of the Arctic Ocean. Therefore, it is clear that the Russian government considers the Arctic to be of huge importance to the country, due to the region's 'resource potential and the geopolitical importance'. The Russian government is especially focusing on the development of oil and gas deposits in the Arctic and has approved a Strategic Programme for Arctic Development to 2020. This programme emphasises the Russian government's willingness to invest in infrastructure and research in the Arctic (Henderson and Loe, 2014, p. 22).

Regardless of Russia's keenness to increase activity in the Arctic waters, the paper by Henderson and Loe (2014, p.37) estimates that we cannot expect significant Russian oil production before 2026. This estimate is based on historical data from Russian Arctic, which shows that the pace of development has been slow and the projects have been plagued by various complications. The development time after discovering a well is assumed to lie between 10 and 12 years (Henderson and Loe, 2014, p. 37). This estimate can of course be further prolonged due to the current sanctions by the Western countries (the US and Europe) against Russia. The sanctions are set due to the conflict between Russia and Ukraine. The conflict is ongoing, thus it is difficult to predict when the sanctions against Russia could be lifted.

Even though the Arctic will always be geopolitically important for Russia, it is not certain that the offshore  oil and gas deposits will be prioritized in the upcoming years due to Russia having various onshore regions left to extract from, such as those in the Yamal Peninsula (Cleas and Moe, 2014, p. 118).

Unlike Russia, Norway does not have many options for expansion of oil extraction, other than the Arctic waters, within its continental shelf. Therefore, the Arctic seems to be a logical next step for Norwegian exploration if the industry is to grow in the coming years, according to Claes and Moe (2014, p.116). Currently Norway has only one active liquefied natural gas (LNG) field in the Arctic, namely the Snøhvit field in the Barents Sea. Norway has 76 active fields in the North Sea and Norwegian Sea, in which the extraction conditions are quite similar to the Barents Sea. This is due to the fact that unlike many other areas above the Arctic Circle, the Barents Sea is almost ice-free year round. The resource potential in the Barents Sea is creating enthusiasm amongst the Norwegian oil industry, and the first Arctic oil field, Goliat, operated by the Italian company ENI, is expected to begin extraction in the Arctic waters in 2015 (Henderson and Loe, 2014, p. 47- 49). However, the current low oil price may postpone many of the Norwegian Arctic projects, including Goliat and one of the world’s most expensive petroleum projects, Johan Castberg (Taraldsen, 2015).

It becomes clear from the study by Henderson and Loe (2014) that the Arctic is a desirable region for oil and gas extraction, but also one that is economically demanding. In addition, the importance of the deposits to the individual countries may become secondary due to lack of demand in the global market. The movement towards renewable energy sources and the development of unconventional oil and gas resources in the US may affect the so-called Arctic race to take a ‘more leisurely pace’, as predicted by Claes and Moe (2014, p.118).

The Arctic region’s role as a future petroleum source is highly debated also due to the effects extraction in the region has on the global climate and the marine ecosystems. In Norway, the debate between what is environmentally conscious and economically profitable in relation to petroleum in the Barents Sea, has been a central feature in the energy development since the

1990's (Jensen, 2007, p.248). Since then, Norway has attempted to adopt the role of the environmentally aware petroleum nation, which should enter the Arctic offshore as quickly as possible in order to help the Russians in extracting oil and gas without putting the environment in risk, according to Jensen (2007, p. 249).

A study by McGlade and Ekins (2014) is the first of its kind in that that it not only quantifies the fossil fuel deposits to be left unburned, in order to reach the UN's goal of two degrees Celsius temperature increase, but also specifies them geographically, according to the cost effectiveness of the development of the deposits. The paper also concludes that new technology such as carbon capture and storage (CCS) is not enough to limit the temperature change below two degrees (2014, p. 105). The study estimates that all of the undiscovered Arctic oil and gas deposits have to remain undeveloped to reach the goal (2014, p. 111).

Due to increased focus on the climate issue and the role of fossil fuels in being able to restrict the temperature increase to two degrees Celsius, the ability of Norway to justify its petroleum activity in the high north through setting environmental standard, may lose its credibility increasingly in the upcoming years. As mentioned above, from a purely economic point of view, it is most optimal to leave the most expensive deposits undeveloped, e.g. the Arctic oil and gas. This is when comparing the fossil fuel deposits on a global scale. However, a country with limited access to expansion in other regions, such as Norway, the Arctic extraction may be the only option for safeguarding the continuation of petroleum production domestically (Henderson and Loe, 2014, p. 40; Claes and Moe, 2014, p. 116).

In the end of the day, the Arctic countries will evaluate the extent of their activity in the Arctic offshore based on domestic politics. In Russia, the political system is very centralized and decisions are taken based on 'expert knowledge', i.e. by a few influential individuals. Thus, the public is much less involved in the decision-making process (Claes and Moe, 2014, p.116). In Norway, the situation is quite different in that that the public is very involved in decision-making, and environmental organisations have a more visible role in politics (Claes and Moe, 2014, p.117). There is a divide in Norway, in regards to extraction in the Barents Sea, where the northern regions seem to be more positive towards oil and gas activity off their coasts, whereas the population in Southern Norway is less enthusiastic about expanding activity (Claes and Moe, 2014, p.117). However, certain areas above the Arctic Circle, such as Lofoten, Vesterålen and Senja (LoVeSe), the locals are not very supportive of the petroleum industry's plans to begin extraction in the far north. The extraction activity in the

LoVeSe region has been put off due to for example the popularity of the People's campaign for oil-free LoVeSe (Folkaksjonen oljefritt LoVeSe)[6]. At the same time, the current reduction in oil income and its side-effects, such as increased unemployment, might make some parties increasingly positive towards extraction in the Arctic, both in Southern, - and Northern Norway.

## 2.2 Removing deposits from the market

According to the paper by Harstad (2012), the problem with current climate coalitions is that nonparticipants may undo the coalition's effort by emitting more than they did before the climate regulations were set. Therefore, this phenomenon called carbon leakage has the potential of reducing the positive impact of the binding climate goals made by the cooperating countries. The ability to remove fossil fuel deposits from the market, thus reducing emissions without a carbon leakage, is suggested by Harstad (2012) and is an interesting approach for the Arctic. Harstad (2012, p.79) defines the expensive deposits as the ones most likely to be able to be removed from the market through deposit trade. This feature characterizes the Arctic deposits very well, according to Lindholt and Glimsrød (2011, p. 10), McGlade and Ekins (2014, p. 111), and Rystad Energy (2013). However, according to Fæhn et al. (2013, p. 4), the ability to remove deposits from the market through deposit trading and commitment to conservation may face various issues. These issues are such as asymmetric information, contract incompleteness, and bargaining failures. Due to the assumption I am making in this paper, that no coalition will ever buy or lease the deposits, it is up to the Arctic nations to evaluate whether or not to develop their Arctic deposits. Fæhn et al. (2013, p. 4) also point out that Norway has yet to take any supply side climate action through restricting extraction. However, the prediction made in this paper is that both Norway and Russia will restrict extraction if developing the undiscovered Arctic fields becomes economically unfeasible due to factors such as changes in the global energy market and reduction in demand for fossil fuels.

Even though the USGS (2008) report found that there is great resource potential in the Arctic, it is extremely important to specify where in the Arctic the resources lie. The Arctic is not a shared resource pool where nations race to dip their straw into, in order to maximize their

[6] See: http://folkeaksjonen.no/ (in Norwegian)

share. Rather, the Arctic is a vast region, covering ca. six percent of the world's surface area (Budzik, 2009, p.2), with a lot of climatic, - and geological variation. This huge region's southern part, where most of the initial extraction would take place, is divided to sub-regions according to country ownership. Therefore, the Arctic countries have to evaluate independently whether the resource potential within their continental shelf is great enough to invest significant funds in Arctic extraction. This is due to the fact that some deposits may be extremely far from the continents, deep under the Arctic Ocean or still covered by the thick ice glaciers, therefore making them less feasible to develop.

The USGS (2008) study points out that the most economically feasible resources lie in the Arctic Alaska (Claes and Moe, 2014, p.105). Also the Russian Arctic has great gas resources identified, as it holds 95 percent of the recoverable natural gas resources in discovered fields (Claes and Moe, 2014, p.106). Norway has not had much luck with finding wells with great potential in the Arctic since it began exploration in the Arctic in 1979. Norway has been looking for oil in the Barents Sea since it was first opened for activity, but so far Snøhvit is the only active field. The next field likely to open in the Norwegian Arctic is the Goliat field, which was approved to operate in 2009 (Claes and Moe, 2014, p.115). Norway has also considered opening the highly debated area of LoVeSe for oil activity, but so far the concerns for destroying the unique nature and great variety of wildlife, has kept the region off the drilling plans. The government of Norway will not be able to reconsider the opening of the area for extraction until the general election in 2017 (Claes and Moe, 2014, p.115).

Taking into consideration the history of the Arctic extraction and the current low oil price, it is likely that at least some of the deposits in the Arctic are viable candidates for being permanently removed from the market. The domestic political conflicts, the sanctions on Russia, the uncertainty regards to the recovery of the oil price, the relatively high costs of extraction, environmental considerations, and the importance of the Arctic deposits in the future energy mix, may contribute to the Arctic nations, such as Russia and Norway to eventually be forced to re-evaluate their Arctic plans. The uncertainty of the amount of oil and gas that is feasible to produce may restrict the extent to which the countries are willing to invest in the Arctic extraction. Only a few seismic surveys and little exploratory drilling have been conducted in the Arctic so far. Therefore, the uncertainty about the expected Arctic resource profits does not only lie in the volatility of the oil price and the unpredictable climate conditions in the offshore (Claes and Moe, 2014, p.118).

As mentioned above, this paper studies the effects that influence the countries' independent decision-making processes and strategies when it comes to the Arctic oil and gas extraction. The countries must have some economic incentive not to extract in order to for the deposits to be permanently removed from the market. The resource potential that lies beneath the Arctic ice provides a strong incentive to proceed with the Arctic extraction. However, the costs of extraction are also great due to the technology requirements, not to mention the risks involved in exploration and extraction activity. These relationships are modeled using game theoretic approach, namely through the war of attrition, in section 3 of this paper.

## 2.3 War of attrition in the Arctic

The game theoretic approach was chosen due to the suitability to the situation in the Arctic in regards to oil and gas extraction. The Norwegian Polar Institute (NPI), in their paper by Izmalkov and Sjøberg (2014), recommends using game theory in the Arctic in order to be able to manage the natural resources in the most effective way. The NPI also recommends the Arctic Council to be granted more of a governing role when it comes to open-access resources, such as fisheries. However, the Arctic Council's impact on oil and gas resources will not be considered in the model developed in this paper, as the council is assumed not be able to have a great influence on the decision making process of extraction of petroleum resources[7]. If anything, the UN may have some say in the distribution of submarine areas that reach beyond 200 nautical miles from the coast of the countries. As both of the countries, Norway and Russia are assumed to commence extraction within their continental shelf, any open access issues that would require a mediator, are irrelevant. Thus, in the model developed in this paper, there is no governing body, only the players whose strategies affect each other. The game theoretic approach used is war of attrition.

The war of attrition is a widely used game theoretic model, which applies to a variety of situations, and was first used by economists to study economic conflicts such as price wars and bargaining (Hendricks et al., 1988, p. 1). The initial application of war of attrition, however, was developed to study the fighting patterns of two animals, fighting over prey, for example. The first animal to stop fighting would lose the prize to the stronger animal. It would also lose all of the energy it has consumed to fight the stronger animal; this is what

[7] Even though the Arctic Council will not operate as a third-party mediator in the model, the influence of the Council is briefly discussed in relation to oil spill prevention and response in section 3.2. of this paper.

economic application regards as the sunk costs. Therefore, if the animal knew that it had no chance of winning the fight, its best option would be to never engage in it. The war of attrition is thus an example of a timing game, according to Fudenberg and Tirole (1991, p. 119). In their book, called *Game Theory*, they present the general model of war of attrition, which, together with the model by Dosi and Moretto (2010), is also the basis for the theory I have developed in this paper. More precisely, the model I have used is the stationary war of attrition that takes place over an infinite number of periods, where three arbitrarily chosen periods will be used to analyse the countries' strategies. In many war of attrition applications, the players cannot commit, in the beginning of the game, to a certain time $t$, at which they will fold the game. In these situations, the players re-evaluate their strategies in each period, given the opponent's strategy. The probability of moving at time $t$ thus becomes the probability of moving *first* at time $t$, given that neither of the two players has moved before it (Hendricks et al., 1988, p. 669).

The paper by Dosi and Moretto (2010) studies the sources of inertia in the process of developing environmental innovations and bringing them to the market, by using a war of attrition game. This theoretical approach is relevant to the Arctic in that that the technology costs seem to play a major role in the ability to extract oil and gas in the Arctic and also in regards to the pace at which the exploration and production (E&P) activities are initiated. Dosi and Moretto (2010, p.42) identify two sources of inertia, i.e. the irreversibility effect in investing in environmental innovations and the second-mover advantage, which results from declining switching costs. These factors apply well to the Arctic, as the petroleum market is very volatile and there is uncertainty about the size and location of the findings. In addition, the technology used in the Arctic offshore is relatively costly. Therefore, it can be assumed that agents, i.e. countries and individual companies, looking to enter the Arctic offshore would prefer to find solutions that reduce their technology costs.

The paper by Dosi and Moretto (2010) studies the companies' research and development (R&D) pace and the factors not only causing inertia, but also causes reducing it. The reduction of development inertia would occur through using a grant, which is assigned to the player who, by a certain point in time, has come furthest in their development process. This player is then rewarded for its efforts by using the grant, thus enabling the firm to bring the innovation to the market. Further, through the technology spillover, the following countries benefit indirectly from the grant and are able to switch to the innovative technology as well (Dosi & Moretto, 2010, p. 48).

Technology innovation is recognised as a factor that reduces production costs. For example, Kahouli-Brahmi (2008, p.139) has identified the technological learning, or the learning effect, as a factor that lowers production costs and follows from increase in cumulative production. The paper identifies various mechanisms of technological learning, one of which is the *learning-by-researching*. This mechanism is 'related to the innovation process and the absorptive capacity of the firm'. Another learning mechanism related to the effect that the technological spillover may create in the Arctic, in the form of reduced capital costs, is the *learning-by-interacting* effect. This effect is described as the 'enhancement of diffusion of knowledge through interactions between laboratories, the industry, the end-users and the political decision-makers' (Kahouli-Brahmi, 2008, p.139).

In the model I have developed in this paper, the countries learn through R&D activities, which allows them to approach the point where they are able to enter the Arctic. As an example, Norway can be assumed to be approximately at this point at the moment, as the Goliat rig is waiting to be shipped to the Arctic offshore. Thus, at this stage of the 'game' Norway can either choose to make the final investments and initiate E&P activities or postpone the entry due to uncertainty of the other country's strategy and of the expected size of the net investment payoff. If Norway decides to enter the Arctic, the technology spillover could then bring the other country, in this case Russia, below the crucial level of capital costs, and incentivise it to enter the Arctic as the second-mover. The different forms of learning-effects reduce the length of the war of attrition game due to technological learning by assumption reducing the capital costs, i.e. the costs of acquiring technology that allows the country to extract resources in the Arctic waters in a cost effective and secure way. However, the factor prolonging the game and postponing entry to the Arctic is the uncertainty of the irreversible investment's payoff. Carruth, Dickerson and Henley (2000) analyse the influence of uncertainty when making irreversible investment decisions. They find that increased uncertainty leads to lower investment rates. The uncertainty effect is measured by using the parameter $\theta_i$, i.e. the perceived opportunity cost of alternative future investment options and the change in the expected investment payoff, $X$. The uncertainty of the payoff from Arctic resources can thus be assumed to affect this parameter in such a way that the option to delay commitment to investment increases (Carruth, Dickerson, and Henley, 2000, p.121).

# 3 The model

The model introduced in this section studies the strategic choices of two Arctic countries, Norway and Russia. I have chosen to use only two players for simplicity, but the war of attrition model developed by Dosi and Moretto (2010) includes N+1 (N>0) players, i.e. any positive number.

The initial situation is one where these two players, N= 2, are planning to extend extraction in the Arctic offshore. The players can choose to enter the Arctic offshore at any moment, given that they have access to the appropriate technology. The final investment in technology, followed by immediate start of E&P activity in the Arctic waters, is irreversible and takes the form $C_i$, $i=1,2$. This investment cost depends on whether the other country has invested and entered the Arctic in a previous period:

$$C_i\,(\theta, q) = \theta_i k(q), \quad i = 1{,}2$$

Where $k(q),\ k > 0$, represents the capital cost, which is common knowledge, and the technology spillover is assumed to affect the countries' capital costs such that:

$$k(q) = \begin{cases} k \ for\ q = 1 \\ k - \Delta_i k \ for\ q = 2 \end{cases}$$

where $k > \Delta_i k > 0$, so that there is an advantage of entering the Arctic second, i.e. when q=2.The parameter $\theta_i \in R^+$is each country's private evaluation reflecting its perception of the opportunity cost of future alternative investment options. These alternative investment opportunities for Russia may be such as oil and gas fields in other regions than the Arctic, and for Norway such as renewable energy.

The costs, $C_i\,(\theta, q)$, represent the full capital costs of the Arctic offshore venture, i.e. the country, by making the investment decision of entering to the Arctic offshore, expects to take on the costs that occur over the full extraction process, from initial drilling to the point where the planned Arctic offshore wells are exhausted. Most of the costs, however, are assumed to accumulate during the pre-production period, i.e. due to technology development, infrastructure transportation and exploration.

As in the model by Dosi and Moretto (2010, p. 41), the importance of the technology spillover depends on the country's private valuation of the alternative investment opportunity cost, $\theta_i$. The higher this perceived opportunity cost is, the more important it is for the country to wait until the other country has entered the Arctic. A high opportunity cost thus increases the option value of waiting and reduces the country's willingness to bear full capital costs that occur when being the first-mover.

The size of the immediate expected investment payoff, $X$, is estimated by the countries, but it will not be known until the countries have entered the Arctic offshore, i.e. until the exploratory wells are drilled. The investment payoff represents the full, expected resource income from the offshore extraction in the Arctic. Thus, $X$ is in reality gained over number of years, but the countries assume that they have a somewhat accurate estimation of the size of $X$ in the investment stage, thus being able to weigh it against the expected costs. In an extension of the model, the investment payoff reduces in every period, thus incentivising the countries to begin extraction in the Arctic as soon as possible.

## 3.1 War of attrition

In the war of attrition game, the players choose the role of a leader or a follower depending on the strategy of the opposing player. The leader enters the Arctic first, and its payoff function at time $t$, where $t$ is the current time, is thus:

$$L(t) = X - \theta_i k = L$$

As the net payoff is discounted in each period by the factor $\delta$, the leader's payoff function in the following period, $t+1$, becomes:

$$L(t+1) = \delta\, L(t) = \delta\, L$$

Where $0 < \delta < 1$. The lower the value of $\delta$ is, the more the country discounts the future payoffs.

The follower's, i.e. the country's that enters the Arctic offshore as second, payoff function is:

$$F(t) = X - \theta_i(k - \Delta_j k\ ) = F$$

Similarly, if the country faces the possibility of entering the Arctic as the second country in the next period, the follower's net payoff function will also be discounted:

$$F(t+1) = \delta F(t) = \delta F$$

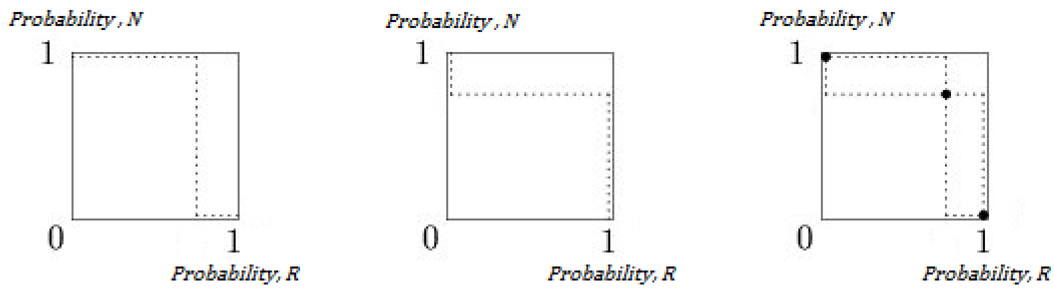
The countries are assumed to invest in the Arctic extraction technology if the net present value (NPV) of their investment is positive. However, both countries evaluate the timing of their entry depending on their perception of the other country's strategy and their private alternative investment opportunity cost, $\theta_i$. Therefore, as in the model by Dosi and Moretto (2010, p. 42), the countries' investment decisions are affected by two sources of inertia. Firstly, the irreversibility effect, i.e. the uncertainty about the investment payoff increases the option value of waiting. Secondly, the technology spillover lowers the second-mover's investment costs. Thus, waiting for the other country to enter first can be more profitable than entering first, even when given the possible losses in income due to postponing extraction. This second source of inertia describes the war of attrition effect, as not knowing the other country's opportunity cost creates a situation where both of the countries would prefer for the other country to enter first, thus being able to learn from their actions and receive the technology spillover.

### 3.1.1 The equilibrium equation

Consider a situation where both players have been in the game for $t$ periods and are evaluating the viability of making the final investment, which allows them to commence extraction immediately.

The stationary game has three Nash equilibria, two of pure strategies and one mixed strategy. For example, the pure strategies may be such that Norway's strategy is "always enter" and Russia's strategy is "never enter", i.e. both countries always play the same, opposite strategy in all periods. In the model I have developed, both countries, however, play a mixed strategy. The equilibria are shown in Fig 2. below.

Fig 2. The equilibria of pure and mixed strategies of Norway and Russia




The left-hand side graph shows the optimum probability of playing the pure strategy for Norway, given Russia's probabilities. The middle graph shows Russia's optimum probability for playing the pure strategy, given Norway's probabilities. In the right-hand side graph, the best response Nash equilibria are shown as points where the lines cross. The pure strategy equilibria are in the far right and far left corners of the square, i.e. where the countries always play opposite strategies. The point where the lines cross in the middle represents the mixed strategy Nash equilibrium, where both players play a mixed strategy. (Templates for graphs from Wikipedia, 2015)

Having mixed strategies makes the countries unpredictable as they re-evaluate their strategies in each period depending on their belief of the other country's strategy (Fudenberg and Tirole, 1991, p. 120). For example, Norway's best response to the Russia's strategy can be modeled such that it enters at time $t$ if $L \geq p_R(\delta F) + (1-p_R)(\delta^2 L)$. Here $p_R$ is the probability that Russia chooses to enter in the next period, and $(1-p_R)$ is the probability that Russia does not enter and Norway gets the leader role in its next decision making period. Norway's probabilities are symmetric to Russia's and denoted by $p_N$ and $(1-p_N)$. Thus, going to the Arctic at time $t$ has to be larger than or equal the probability of Russia entering the Arctic in the next period, therefore being able to benefit from the technology spillover, plus the probability of having to go as a leader in the period after. Therefore, as the countries are not making decisions simultaneously, but taking turns and observing each-others' actions, the payoff of being a follower in the next period has to be discounted as well.

Therefore, as explained by Fudenberg and Tirole (1991, p.120), in a mixed strategy, for any $p$, "always $p$" is the behavior strategy "if the other country has not entered the Arctic before $t$, then enter at t with probability $p$". The equivalent strategic form mixed strategy allocates probability $(1-p)$ to the strategy "enter at $t$ if the other country has not entered before then."

In a symmetric equilibrium both countries need to be indifferent between entering and not entering, i.e. both options have to be best responses to the other country's strategy. The equilibrium equation of either of the countries, when indifferent between entering now and waiting another period, is:

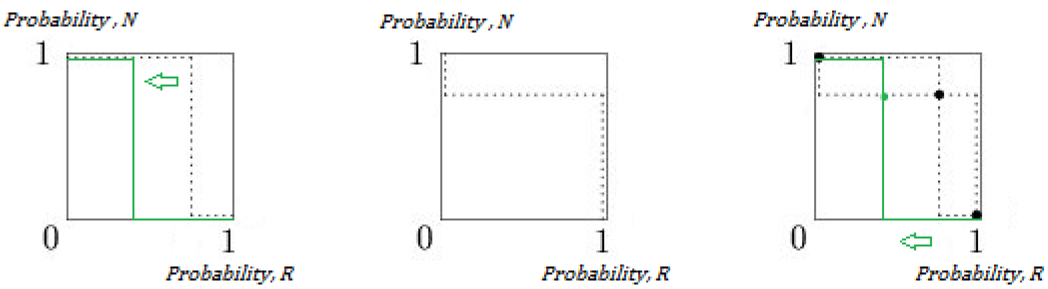
$$L = p(\delta F) + (1\text{-}p)\,(\delta^2 L)$$

Where the payoff of entering at $t$, conditional on the opponent not having entered before $t$, $L$ is equal to the payoff of staying until $t{+}2$ and entering then unless the opponent enters in the next period, $t{+}1$.

As mentioned above, the countries are heterogenetic in their perception of opportunity cost for alternative future investment options, measured by $\theta_i$. In addition the technology spillover varies between the countries. The spillover, measured by $\Delta_i k$ , is assumed to be greater to from Norway to Russia, than the spillover from Russia to Norway. Due to these heterogeneities, the countries' probabilities will differ.

In equilibrium, if parameter values of one country change, thus changing the willingness of that country to enter the Arctic as the first-mover, the opposing country will adjust its probabilities to maintain the equilibrium where both countries are indifferent between staying in the game and entering the Arctic, thus ending it. The situation where Norway's willingness to enter is reduced, for example due to an increase in the perceived opportunity cost for alternative future investment options, is illustrated in Fig 3. below:

Fig 3. The reduction in Norway's willingness to enter the Arctic.




The graph on the left-hand side shows how an increase in for example Norway's opportunity cost can reduce the country's willingness to enter the Arctic as the first-mover. Russia's parameters remain the same, as seen in the middle graph. The graph on the right-hand side shows how Russia must adjust its probabilities in the mixed strategy equilibrium. Thus, the increase in Norway's opportunity cost has affected negatively on the probability of Russia entering the Arctic as the first-mover. The pure strategy equilibria in the far right, - and far left corners remain of course the same. (Templates for graphs from Wikipedia, 2015)

### 3.1.2 Solving the equilibrium equation for Norway and Russia

In the simplest form of the game, the immediate investment payoff, $X$ is assumed constant. The countries' capital cost, $k(q)$ when $q=1$, is assumed to be common knowledge and equal for both players. Therefore, as mentioned above, the heterogeneity of the countries' net benefit, $X - C_i$, comes from the variation between the size of the technology spillover, $\Delta_j k$ , and their private alternative future investment opportunity cost, $\theta_i$.

Thus, starting with Norway's equilibrium equation to be indifferent between entering now and waiting to go second in the next period or as the leader in the period after:

$$X - \theta_N k = p_R[\delta(X - \theta_N\ (k - \Delta_R k)] + (1 - p_R)[\ \delta^2(X - \theta_N k)]$$

Solving for the probability, $p_R$, gives:

$$p_R = \frac{X - \theta_N k - \delta^2\ (X - \theta_N k)}{\delta(X - \theta_N\ (k - \Delta_R k) - \delta^2\ (X - \theta_N k)} = \frac{X - \theta_N k - \delta^2 X + \delta^2 \theta_N k}{\delta X - \delta\theta_N\ k + \delta\theta_N \Delta_N k - \delta^2 X + \delta^2 \theta_N k} = \frac{F}{G}$$

In order to simplify the function, F and G denote the numerator and denominator, respectively.

Similarly, Russia's equilibrium equation to be indifferent is as follows:

$$X - \theta_R k = p_N[\delta(X - \theta_R\ (k - \Delta_N k))] + (1 - p_N)[(\delta^2 (X - \theta_R k)]$$

Thus, solving this for $p_N$ gives:

$$p_N = \frac{X - \theta_R k - \delta^2 (X - \theta_R k)}{\delta(X - \theta_R\ (k - \Delta_N k) - \delta^2\ (X - \theta_R k)} = \frac{X - \theta_R k - \delta^2 X + \delta^2 \theta_R k}{\delta X - \delta\theta_R\ k + \delta\theta_R \Delta_N k - \delta^2 X + \delta^2 \theta_R k} = \frac{F}{G}$$

Where $\Delta_N$ is the technology spillover from Norway to Russia and $\Delta_R$ is the technology spillover from Russia to Norway, i.e. $\Delta_N k > \Delta_R k$, and, due to for example domestic politics and energy policies, $\theta_N \neq \theta_R$. F and G represent the numerator and denominator also for Russia's equilibrium equation. Therefore, for both countries, F and G are as follows:

F = $X - \theta_j k - \delta^2 X + \delta^2 \theta_j k$ and G = $\delta X - \delta\theta_j\ k + \delta\theta_j \Delta_i k - \delta^2 X + \delta^2 \theta_j k$

Where the countries are assigned identifications *i* and *j*.

Taking the first order conditions with respect to the parameters $\theta_j, \Delta_i k, X, k,$ which are symmetrical for both countries. The derivations could apply to any two players, $i$ and *j*, where $i \neq j$:

The first order conditions:

$$\frac{dp_i}{d\theta_j} = \frac{Gk(\delta^2-1)-F(-\delta k+\delta\Delta_i k+\delta^2 k)}{G^2} < 0$$

$$\frac{dp_i}{d\Delta_i k} = \frac{-F\delta\theta_j}{G^2} < 0$$

$$\frac{dp_i}{dX} = \frac{G(1-\delta^2)-F(\delta-\delta^2)}{G^2} > 0$$

$$\frac{dp_i}{dk} = \frac{G(-\theta_j+\delta^2\theta_j)-\mathrm{F}(-\delta\theta_j+\delta^2\theta_j)}{G^2} < 0$$

Note that the derivatives are either positive or negative due to the assumption that the countries' NPVs are positive in the equilibrium equations.

**Proposition 1.** *In the mixed strategy equilibrium, the changes in country j's parameters affect its willingness to enter the Arctic and thus country i's probability of entering the Arctic as the first-mover as well.*

*(i) The opportunity cost of alternative future investments,* $\theta_j$*: The larger is the country's j's opportunity cost is, the less willing it is to enter the Arctic and the less probable it is for country i to enter the Arctic as the first-mover.*

*(ii) The technology spillover,* $\Delta_i k$*: As the size of the expected technology spillover increases, the higher becomes the preference of the country j to enter as the second-mover, and the lower the probability of i entering as a first-mover.*

*(iii) The expected investment payoff,* $X$*: The probability of entering first increases for both countries as the size of the expected investment payoff increases.*

*(iv) The capital cost,* $k$*: The larger the capital costs are, the less likely are the countries to be willing to enter the Arctic offshore.*

**Explanation of proposition 1.**

(i) The opportunity cost of alternative future investments, $\theta_i$: The derivative of country *i*'s probability with respect to the effect of country *j*'s opportunity cost, $\frac{Gk(\delta^2-1)-F(-\delta k+\delta\Delta_i k+\delta^2 k)}{G^2}$, is negative for all values. Therefore, we can see that an increase in country *j*'s opportunity cost decreases country *i*'s probability of entering the Arctic as the first-mover.

(ii) The technology spillover, $\Delta_i k$: The derivative of the probability, $p_{i,}$ with respect to the technology spillover, $\Delta_i k$, is always negative, as the numerator is always negative and the denominator positive: $\frac{-F\delta\theta_j}{G^2}$. I.e. an increase of the expected technology spillover to country *j* from country *i* increases the willingness of country *j* to become a second-mover, and thus reduces country *i*'s probability of entering as the first-mover.

(iii) The expected investment payoff, $X$: If the expected payoff for country *j* were to increase, the willingness of *j* to enter as the first-mover would increase, also increasing the probability of country *i* entering first to the Arctic. We can see this as the partial derivative of the probability of country *i* with respect to the payoff is positive for all values, $\frac{G(1-\delta^2)-F(\delta-\delta^2)}{G^2}$.

(iv) The capital cost, $k$: As seen from the negative derivative of the probability of country *i* with respect to the capital costs of country *j*[8], $\frac{G(-\theta_j+\delta^2\theta_j)-\mathrm{F}(-\delta\theta_j+\delta^2\theta_j)}{G^2}$, the increase in country *j*'s costs would reduce country *j*'s willingness to enter the Arctic, and also country *i*'s probability of becoming the first-mover.

# 3.2 The probability of excess costs due to an oil spill

The probability of an oil spill exists in the Arctic offshore in the same way as in any region where there is offshore oil activity. The Arctic region can be, however, due to its challenging nature, even more exposed to the risk of an oil spill than other offshore regions. The potential damages in the Arctic may also be greater compared to regions that are closer to infrastructure

[8] The capital costs, *k*, are, however common for both countries when no spillover occurs, therefore the increase in country *j*'s costs would also mean that country *i*'s costs are increased.

and have year-round daylight. However, the risk of an oil spill taking place and the potential damages can naturally also vary greatly within the Arctic. The Arctic Russia is characterized by shallow waters and year-round ice cover, whereas the Norwegian part of the Barents Sea is partly completely ice free, but has deeper waters.

The factors affecting oil spill prevention, response and recovery can be such as:

- response time after oil spill
- size of the leakage (pace at which petroleum is leaking)
- season (length of day, extent of ice coverage in the surrounding sea)
- weather conditions
- available technology and size of rescue crew
- location and size of the spill (oil under the ice or close to especially vulnerable ecosystems, such as those at the ice edge)
- level of difficulty in blocking the leakage

All of these factors are important in that that they might create great variations to the costs, thus the countries looking to extract oil and gas in the Arctic, have to take into consideration these points and naturally aim at minimising the probability of an oil spill taking place.

The probability of an oil spill depends mainly on how well the countries are prepared for entering the Arctic offshore. In 2012, the Royal Dutch Shell's drilling rig, Kulluk, ran ashore in Sitkalidak Island in Alaska. This time an oil spill was avoided as the containers filled with diesel fuel and lubricant were left undamaged in the middle of the rig (Lavelle, 2014). This accident, however, created skepticism about Shell prioritising the security of the rigs and raised accusations of the company putting the Arctic waters in jeopardy due to its recklessness.

During the spring of 2015, as Shell was preparing to re-enter the Chukchi Sea and Statoil's Arctic oilrig, Goliat, arrived to Hammerfest to be sent to the Arctic waters, the fifth anniversary of history's greatest offshore oil spill, the Deepwater Horizon, was celebrated.

On April 20 in year 2010, the Deepwater Horizon oilrig exploded in the Gulf of Mexico, leaking out approximately 4.9 million barrels of oil and killing 11 workers. The spill, also known as the Macondo oil spill, created over $40 billion US dollars in clean-up costs and legal liabilities to the oil company British Petroleum (BP). Since the accident, the offshore E&P activities and risks related to them have been reviewed by the various disciplines, from politicians to academics, according to Vinogradov (2013, p. 335, 340). Even though an oil spill of this magnitude is highly unlikely to happen in the Arctic, as the companies and countries are, through cooperation and independent R&D, looking for solutions to prevent any oil spills, smaller, intentional or unintentional spills are perhaps more likely to occur.

Vinogradov (2013, p.337) describes the various ways the different types of pollution may enter the environment from offshore E&P activities:

‘*They [offshore E&P operations] involve the extraction of petroleum, require the use of potentially harmful substances (oil based drilling muds and chemicals), and entail various discharges and emissions. There are four main stages of offshore petroleum development: geological and physical surveying; exploration; development and production; and decommissioning. Each of these stages is associated with some actual or potential environmental impact, which manifests itself in the form of physical, chemical, and biological disturbances in the water column, on the seabed, and in the atmosphere. Pollution occurs at all stages of offshore E&P and involves more than 800 substances, dominated by oil and oil products*’.

Thus, the agents looking to extract oil and gas in the Arctic, have to aim at minimising not only accidental oil spills, but also sources of pollution that occur at different production stages.

The Arctic oil and gas extraction activity requires especially strict requirements, due to the challenging conditions that characterize the region. As the deep-water technology is improving and most of the remaining deposits owned by non-OPEC countries lie offshore, the petroleum companies are moving further offshore, to more demanding areas, and not just in the Arctic (Vinogradov, 2013, p. 336). With this trend, also regulations and guidelines for the offshore industry have to be further developed.

The impact of an accidental oil spill can be dramatic to the Arctic marine ecology and have catastrophical consequences to the whole oil industry (Winkler et al., 2015), but as Vinogradov  (2013, p.337) points out, extraction creates pollution in many different forms, which all have to be considered when weighing the costs of extraction against the benefits. In order for the offshore companies to be able to extract oil and gas responsibly in the offshore, various policy frameworks are applied. For example, the northeast Atlantic region is operated under the Oslo-Paris (OSPAR) Convention that provides guidelines for operational pollution (Vinogradov, 2013, p.344). The OSPAR agreement covers the Barents Sea but not the Kara Sea, as shown below in Fig 4.

Fig. 4. The OSPAR Convention area is divided into five regions, first of which is the Arctic Waters (OSPAR Commission, 2015)


The oil and gas activities between Norway and Russia are regulated by a bilateral OSR Agreement, which was initiated in 1994. The Agreement includes a joint contingency plan, joint training exercises and a joint planning procedure in the border region, according to Knol and Arbo (2014, p. 172). In addition, the Arctic Council has several scientific working groups, which aim at solving Arctic issues, in regards to oil and gas activity, amongst others. The working groups study and analyse for example prevention, preparedness and response to oil spills and sustainable use of the Arctic environment. In 2011, the Arctic Council signed a legally binding contract for Search and Rescue operations in the Arctic (SAR). This contract was followed by a binding agreement to 'strengthen cooperation, coordination and mutual assistance among the parties on oil pollution preparedness and response in the Arctic in order to protect the marine environment from pollution by oil' as described by Knol and Arbo (2014, p. 172). Both Norway and Russia are member states in the Arctic Council. Thus, the countries have to make sure that they meet the requirements of the various global and regional agreements in addition to making their internal cost-benefit analyses in regards to spill prevention.

From a purely economic point-of-view, it is beneficial for the countries extracting oil and gas in the offshore to take any precautions possible in order to avoid any accidental oil spills. According to the European Commission, the cost of a major oil spill in the EU waters would range from €205 million to €915 million (Vinogradov, 2013, p.350). Considering that the Arctic waters are relatively challenging compared to the average maritime conditions in Europe, the costs would most likely be up on the top of the scale, rather than in the bottom of it. Knol and Arbo (2014, p. 175) point out that the Arctic is especially vulnerable to oil spills due to for example low water temperatures that mean that the hydrocarbons persist in the water for longer than in warm waters. In order to get an idea of the worst-case scenario and the magnitude of the expected response and recovery ability, Knol and Arbo (2014, p.175) highlight that the Deepwater Horizon accident required '48 000 people, 6500 vessels and 125 aircrafts at the peak of the clean-up process'. Thus, companies or even single countries cannot plan recovery of extensive oil spills alone, even though they may have the ability to control small-scale spills. In case of a larger-scale spill, international cooperation becomes most certainly necessary, in order to be able to react to the pollution quickly and effectively. Therefore, it is beneficial for the Arctic oil and gas companies to share knowledge and technology when it comes to the safety of E&P activities (Winkler et al., 2015).

According to Frynas (2013, p. 1), oil companies are relatively good at corporate social responsibility (CSR) as the damages from accidents are potentially extremely visible and costly – directly due to recovery costs and indirectly due to worsened reputation. However, voluntary precautions i.e. CSR, seem often to be motivated by current and expected environmental regulations (Frynas 2013, p. 6). Therefore, it can be assumed that also due to the high media visibility and public interest, the countries looking to extract in the Arctic offshore would take extreme measures in order to minimize the probability of an oil spill occurring. Unfortunately, as we have learned from the Deepwater Horizon accident, the accidental oil spills can be caused, not only due to poor technology, but also due to human error. In the case of the Deepwater Horizon, the reason behind the accident was a combination of these two (The Encyclopedia of the Earth, 2011). The countries can thus maximise the safety of their oilrigs and transportation methods, but it is nearly impossible to remove the risk of an oil spill completely, due to the fact that we are only humans and can make mistakes.

The previews of what can happen if necessary precautions are not taken, offered by such accidents as the Deepwater Horizon and the close-call of Kulluk, when entering the Arctic offshore, has emphasized the need to develop the extraction, transportation, and exploration technology to such a level that the risk of any Arctic disasters is avoided. Therefore, an extension is made to the war of attrition model analysed above. In this extension, a risk of an oil spill increases the expected costs of Arctic E&P activities. However, as both the countries, Norway and Russia, are assumed to be constantly developing their oil spill preparedness and prevention, the longer they wait to enter the offshore, to less likely it is that an oil spill will occur. There is assumed to be no second-mover advantage in relation to the oil spill risk, i.e. there is no response and recovery technology spillover from one country to another. However, the countries may share technology and cooperate in reducing the risks, in contrast to the extraction technology related to production efficiency, which in this model is only shared through unintentional spillovers. This is because, as mentioned above, countries tend to want to cooperate in reducing oil spill risks, as this is equally beneficial to all the involved parties. Sharing operational secrets and innovations, however, is not necessarily beneficial in the same way, unless the countries have a co-operational agreement.

### 3.2.1 The equilibrium equation

In the situation where both countries consider the possibility of an oil spill taking place at some point during the exploration and extraction activity, the equilibrium equations include the probability of an oil spill, $0 < \gamma_i^t < 1$. The probability of an oil spill reduces with time, i.e. the longer the country waits to enter the Arctic offshore, the less likely it is to cause an oil spill, therefore $\gamma_i^t > \gamma_i^{t+1}$. If the oil spill occurs, it increases the country's costs by $R_i > 0$. The cost of an oil spill can thus be any positive amount. Therefore, the expected costs occurring due to an oil spill reduce in every period that the country stays in the game, i.e. $\gamma_i^t R_i > \gamma_i^{t+1} R_i$.

The equilibrium equation to be indifferent between entering the Arctic or waiting for another period of the countries remains the same as before, except that the leader's and the follower's net benefits now depend on time. For example, if $t=0$, i.e. $t$ is the current moment:

$$L(t) = p\,(\delta F(t+1)) + (1-p)\,(\,\delta^2 L(t+2))$$

Where the payoff of entering at $t$, conditional on the opponent not having entered before $t$, $L(t)$, is equal to the payoff of staying until $t+2$ and entering then unless the opponent enters in the next period, $t+1$. However, in the situation where the probability of an oil spill is taken into consideration, the countries' benefit from postponing their entry to the Arctic.

The countries may perceive the risk of an oil spill differently due to the different E&P conditions and the assumption of heterogenetic technology. Therefore, one country's option value to wait another period may be increased greatly due to the periodic reduction in the perceived risk of oil spill, whereas another country may find that their technology development is at an acceptable stage, thus improving the technology for an additional period will not lower the risk probability in a significant way. The cooperation between countries in prevention and recovery technology development also suggests that the level of development of this type of technology is not correlated with the country's E&P technology development, e.g. Russia may have relatively developed risk reduction technology due to the international cooperation, even though its E&P technology is assumed relatively little developed.

### 3.2.2 Solving the equilibrium equation for Norway and Russia

In this extension of the model, the heterogeneity of the countries' net benefit, $X - C_i$, does not only come from the variation between the size of the technology spillover, $\Delta_j k$, and their private alternative future investment opportunity cost, $\theta_i$, but also from the variation of the expected costs of an oil spill, $\gamma_i^t R_i$.

Starting with Norway's equilibrium equation to be indifferent, at time $t$:

$$\delta^t(X-(\theta_N k+\gamma_N^t\, R_N)) = p_R[\delta^{t+1}\,(X-(\theta_N(k-\,\Delta_R k)+\gamma_N^{t+1}R_N\,))] + (1-p_R)\,[\delta^{t+2}(X-(\theta_N k+\gamma_N^{t+2}\,R_N))]$$

Solving for the probability, $p_R$, gives:

$$p_R = \frac{\delta^t(X-(\theta_N k + \gamma_N^t R_N)) - \delta^{t+2}(X - (\theta_N k + \gamma_N^{t+2} R_N))}{\delta^{t+1}[X - (\theta_N (k - \Delta_R k) + \gamma_N^{t+1} R_N)] - \delta^{t+2}(X - (\theta_N k + \gamma_N^{t+2} R_N))}$$

$$= \frac{X - \theta_N k - \gamma_N^t R_N - \delta^2 X + \delta^2 \theta_N k - \delta^2 \gamma_N^{t+2} R_N}{\delta X - \delta\theta_N k + \delta\theta_N \Delta_R k - \delta\gamma_N^{t+1} R_N - \delta^2 X + \delta^2\theta_N k - \delta^2 \gamma_N^{t+2} R_N} = \frac{F}{G}$$

Where F and G, again, denote the numerator and denominator, respectively.

Similarly, the equilibrium equation for Russia is:

$$\delta^t(X - (\theta_R k + \gamma_R^t R_R)) = p_N[\delta^{t+1}(X - (\theta_R(k - \Delta_N k) + \gamma_R^{t+1} R_R))] + (1 - p_N)[\delta^{t+2}(X - (\theta_R k + \gamma_R^{t+2} R_R))]$$

Solving for the probability, $p_N$, gives:

$$p_N = \frac{\delta^t(X - (\theta_R k + \gamma_R^t R_R)) - \delta^{t+2}(X - (\theta_R k + \gamma_R^{t+2} R_R))}{\delta^{t+1}[X - (\theta_R (k - \Delta_N k) + \gamma_R^{t+1} R_R)] - \delta^{t+2}(X - (\theta_R k + \gamma_R^{t+2} R_R))}$$

$$= \frac{X - \theta_R k - \gamma_R^t R_R - \delta^2 X + \delta^2 \theta_R k - \delta^2 \gamma_R^{t+2} R_R}{\delta X - \delta\theta_R k + \delta\theta_R \Delta_N k - \delta\gamma_R^{t+1} R_R - \delta^2 X + \delta^2\theta_R k - \delta^2 \gamma_R^{t+2} R_R} = \frac{F}{G}$$

Where $\Delta_N > \Delta_R$, $\theta_N \neq \theta_R$ and $\gamma_N^t R_N \neq \gamma_R^t R_R$.

In order to simplify the equilibrium equation, the numerator and denominator for both countries' equilibria are assigned letters F and G, i.e.:

$$F = X - \theta_j k - \gamma_j^t R_j - \delta^2 X + \delta^2 \theta_j k - \delta^2 \gamma_j^{t+2} R_j \text{ and } G = \delta X - \delta\theta_j k + \delta\theta_j \Delta_i k - \delta\gamma_j^{t+1} R_j - \delta^2 X + \delta^2 \theta_j k - \delta^2 \gamma_j^{t+2} R_j$$

Where the countries are given identifications *i* and *j*.

Taking the first order conditions with respect to the parameters $R_j, \Delta_i k, X, \theta_i, \gamma_j^t, k,$ which are symmetrical for both countries. Thus the derivations could apply to any two players, $i$ and $j$, where $i \neq j$:

The first order conditions:

$$\frac{dp_i}{dR_j} = \frac{G\left(-\gamma_j^t - \delta^2\gamma_j^{t+2}\right) - F(-\delta\gamma_j^{t+1} - \delta^2\gamma_j^{t+2})}{G^2} < 0$$

$$\frac{dp_j}{d\Delta_i k} = \frac{-F\delta\theta_j}{G^2} < 0$$

$$\frac{dp_i}{dX} = \frac{G(1-\delta^2) - F(\delta - \delta^2)}{G^2} > 0$$

$$\frac{dp_i}{d\theta_j} = \frac{Gk(\delta^2 - 1) - F(\delta^2 k - \delta k + \delta\Delta_i k)}{G^2} < 0$$

$$\frac{dp_i}{d\gamma_j^t} = \frac{G\left(-R_j - \delta^2\gamma_j^2 R_j\right) - F(-\delta\gamma_j R_j - \delta^2\gamma_j^2 R_j)}{G^2} < 0$$

$$\frac{dp_i}{dk} = \frac{G(-\theta_j + \delta^2\theta_j) - \mathrm{F}(-\delta\theta_j + \delta^2\theta_j)}{G^2} < 0$$

Note that the derivatives are either positive or negative due to the assumption that the countries' NPVs are positive in the equilibrium equations.

**Proposition 2.** *In a mixed strategy equilibrium, the changes in parameters of country j affect willingness of country j and the probabilities of the opposing country i to enter the Arctic as the first-mover, now adding the risk of an oil spill,* $\gamma_j^t R_j$*, which is assumed to increase a country's option value of waiting.*

*(i) The size of the costs of the expected oil spill,* $R_j$*: The higher the country j's expected size of the oil spill is, the less willing becomes the country j to enter the Arctic as the leader, thus reducing the probability of the opposing country, i, to become a first-mover.*

*(ii) The technology spillover,* $\Delta_i k$*: The larger the expected technology spillover from country i is, the smaller becomes the willingness of country j to enter the Arctic first, therefore reducing the probability of country i entering as the first-mover as well.*

*(iii) The expected investment payoff,* $X$*: The higher the expected investment payoff, the more likely it is for both of the countries to enter the Arctic first.*

*(iv) The opportunity cost of alternative future investments,* $\theta_j$*: The larger the country j's private evaluation of the alternative opportunity cost for investments in the future is, the lower becomes the willingness of country j to enter the Arctic and thus the probability of the opposite country, i entering the Arctic first reduces as well.*

*(v) The probability of an oil spill occurring, $\gamma_j^t$: The probability of an oil spill occurring, perceived by country j, postpones its entry to the Arctic and reduces the country i's probability of entering the Arctic as the first-mover.*

*(vi) The capital cost, $k$: The larger the capital costs are, the less likely are the countries to be willing to enter the Arctic.*

**Explanation of proposition 2.**

(i) The size of the costs of the expected oil spill, $R_j$: The larger the expected oil spill is, the more likely it is, in equilibrium, for the country *j* to postpone its entry and therefore for country *i*'s probability to enter first reduce accordingly. This can be seen, as the derivative of the probability of *i* with respect to the size of the oil spill costs, $\frac{G\left(-\gamma_j^t-\delta^2\gamma_j^{t+2}\right)-F(-\delta\gamma_j^{t+1}-\delta^2\gamma_j^{t+2})}{G^2}$, is negative for all values.

(ii) The technology spillover, $\Delta_i k$: The technology spillover from country *i* to country *j* reduces country *j*'s willingness to enter the Arctic as the first-mover, therefore reducing the probability of country *i* entering first as well. This is proven by the negative derivative of country *i*'s probability with respect to the size of the spillover to country *j*, $\frac{-F\delta\theta_j}{G^2}$.

(iii) The expected investment payoff, $X$: The derivative of the probability of country *i* entering the Arctic first with respect to the expected payoff of country *j* is positive for all possible values; $\frac{G(1-\delta^2)-F(\delta-\delta^2)}{G^2}$. This increase in country *j*'s expected payoff thus increases country *j*'s willingness to enter the Arctic and country *i*'s probability of entering first.

(iv) The opportunity cost of alternative future investments, $\theta_j$: Due to country *j*'s private evaluation of the alternative opportunity cost increases, it becomes less willing to enter the Arctic. Therefore, as we can see from the derivative, which is negative for all values, $\frac{Gk(\delta^2-1)-F(\delta^2k-\delta k+\delta\Delta_i k)}{G^2}$, the probability of country *i* entering the Arctic as the first-mover is also reduced.

(v) The probability of an oil spill occurring, $\gamma_j^t$: The increase in probability of an oil spill occurring reduces country *j*'s willingness to enter to the Arctic, as it would prefer to wait and thus reduce the probability of the accident taking place. The country *i*'s probability of entering is reduced as a consequence, as seen from the derivative, which is negative for all possible values, $\frac{G\left(-R_j-\delta^2\gamma_j^2R_j\right)-F(-\delta\gamma_jR_j-\delta^2\gamma_j^2R_j)}{G^2}$.

(vi) The capital cost, $k$: The capital costs reduce the countries' willingness to enter the Arctic, as illustrated by the negative derivation of the probability of country *i* entering the Arctic as a first-mover with respect to the effect of the capital costs, $\frac{G(-\theta_j+\delta^2\theta_j)-\mathrm{F}(-\delta\theta_j+\delta^2\theta_j)}{G^2}$.

## 3.3 Reduction in investment payoff

Due to the current political climate, the future of the global energy mix is very unpredictable. The world's population is growing and developing countries are increasing their energy use due to economic growth and modernization. This creates hope for the petroleum industry due to the assumption that in order to be able to meet the future demand levels, new deposits have to be discovered and developed. However, due to the fallen oil prices, some developments have slowed down and the industry prospects have become more uncertain.

Meanwhile, the renewable energy sources are getting more and more wind under their sails, and may threaten the fossil fuel industries' growth possibilities, as the world is turning to carbon neutral energy options in order to reduce the greenhouse effect. For example, solar power is becoming more affordable and thus increasing in popularity, globally. This creates a threat to the fossil fuel industries, as energy is a homogenous good, i.e. consumers will prefer to buy and invest in the cheapest energy source – environmental considerations taken into account or not. This makes renewable energy substitutes especially dangerous for the fossil fuel industry. As an example, on April 30th, 2015, the electric car company, Tesla, introduced its new line of business, namely renewable energy production for homes and buildings. The company unveiled the technological innovation, the *Powerwall*, which is a new, more effective and sleek battery that allows its users to use 100 percent solar power in their homes when the sun is not shining. Tesla's battery solution is made available to all consumers, whether or not they are connected to a power grid. The estimate made by the company is that you can power homes, commercial buildings and transportation, globally, by using two billion *Powerpacks*, which are more powerful than the *Powerwalls*, more specifically, they are large-scale batteries, 'designed to scale infinitely and reach the gigawatt hour -class', as described by Tesla's representative, Elon Musk in his launch event speech (Tesla Motors, 2015). It remains to be seen if Tesla and other companies within the renewable energy industry can replace fossil fuels in the energy mix, but the risk for that happening is realistic. This kind of new, innovative energy technology has the potential to push the fossil fuels off the market, as the ability to harness the free[9], renewable energy becomes possible in a large scale and with competitive prices.

As mentioned above, especially the most expensive deposits, such as those in the Arctic offshore, may be at risk of not being feasible to develop (Parkinson, 2015). Therefore, I am assuming that the expected profits from Arctic extraction are reduced the longer the country waits before entering the offshore.

The stranded asset risk may also become larger in the upcoming years. In the beginning of 2015, divestment campaigns, such as the Guardian's *Keep it in the Ground*- campaign, gained a lot of attention in the media[10]. Many public funds have pulled their investments out of fossil fuels, coal being the main focus of these divestments, but oil and gas getting their share of bad publicity. As an example, in April 2015, the Church of England sold £12m worth of investments on tar sands oil and thermal coal (Vaughan, 2015). Thus, the threat of stranded assets, introduced more thoroughly above, can be a factor that will affect the future profit expectations from Arctic oil and gas, in addition, or rather together with, the threat of a backstop technology[11] taking over the market.

As the immediate expected payoff, $X$, is in this model, in theory, gained as soon as the country makes the investment required to be able to enter the Arctic, I will measure the reduction through using the parameter $0 < \sigma_i^t < 1$. As the parameter reduces as $t$ grows larger, the payoff is assumed larger if the country enters the offshore in period $t$ rather than $t+1$, ceteris paribus. Thus, $\sigma_i^t X > \sigma_i^{t+1} X$, i.e. the earlier period payoff is strictly larger than the following period payoff. The longer the country waits to enter the Arctic, the shorter its expected production time will be and therefore, the smaller the net profits are.

[9] By free I do not refer to technology harnessing the energy, but the energy that we get from for example the sun, which is known to produce energy without any operational costs.
[10] See: http://www.theguardian.com/environment/series/keep-it-in-the-ground
[11] Backstop technology can be for example any renewable energy source, use of which becomes more profitable than the use of oil and gas, especially from the Arctic.

### 3.3.1 The equilibrium equation

In this case where both of the countries acknowledge that the payoff, $X$, will reduce with time, the equilibria equations include the additional discount factor on profit, $\sigma_i^t$. This discount factor may differ between the two countries but not significantly. This is because the profit reduction is based on changes in the global energy market, which therefore affect both, Norway's and Russia's ability to export oil and gas. However, the Russian and Norwegian Arctic offshore deposits differ in such that Norway has a larger expected share of oil compared to Russia, which is expected to find mainly gas off its shores. Therefore, it can be assumed that Norway is more dependent on the demand of oil whereas Russia's income depends on the demand for gas.

The equilibrium equation to be indifferent between entering in the current period, $t$, or staying in the game remains the same as before:

$$L(t) = p\,(\delta F(t+1)) + (1-p)\,(\delta^2 L(t+2))$$

Where the payoff of entering at $t$, conditional on the opponent not having entered before $t$, $L(t)$, is equal to the payoff of staying until $t+2$ and entering then unless the opponent enters in the next period, $t+1$.

### 3.3.2 Solving the equilibrium equation for Norway and Russia

Unlike in the situation where the war of attrition game was extended to include a risk of an oil spill, the reducing payoff extension creates a motivation to enter the Arctic offshore faster, rather than slower.

In addition to evaluating their current opportunity costs of future alternative investments, $\theta_i$, and the likelihood of receiving a technology spillover, $\Delta_j k$, the countries also take into account the reductions in expected investment payoffs, $X$, i.e. they now become discounted with parameter $0 < \sigma_i^t < 1$. Therefore, as mentioned above, the payoffs reduce with time, i.e. $\sigma_i^t X > \sigma_i^{t+1} X$.

Starting with Norway's equilibrium equation to be indifferent between entering and staying in the game:

$$\delta^t(\sigma_N^t X - \theta_N k) = p_R\,[\delta^{t+1}(\sigma_N^{t+1} X - \theta_N(k - \Delta_R k))] + (1 - p_R)[\delta^{t+2}(\sigma_N^{t+2} X - \theta_N k)]$$

Solving for the probability, $p_R$, gives:

$$p_R = \frac{\delta^t(\sigma_N^t X - \theta_N k) - \delta^{t+2}(\sigma_N^{t+2}X - \theta_N k)}{\delta^{t+1}(\sigma_N^{t+1}X - \theta_N(k - \Delta_R k)) - \delta^{t+2}(\sigma_N^{t+2}X - \theta_N k)} = \frac{\sigma_N^t X - \theta_N k - \delta^2\sigma_N^{t+2}X + \delta^2\theta_N k}{\delta\sigma_N^{t+1}X - \delta\theta_N k + \delta\theta_N\Delta_R k - \delta^2\sigma_N^{t+2}X + \delta^2\theta_N k} = \frac{F}{G}$$

Where F and G denote the numerator and denominator, respectively.

Russia's equilibrium equation to be indifferent is as follows:

$$\delta^t(\sigma_R^t X - \theta_R k) = p_N\,[\delta^{t+1}(\sigma_R^{t+1}X - \theta_R(k - \Delta_N k))] + (1 - p_N)[\delta^{t+2}(\sigma_R^{t+2}X - \theta_R k)]$$

Solving for the probability, $p_N$, gives:

$$p_N = \frac{\delta^t(\sigma_R^t X - \theta_R k) - \delta^{t+2}(\sigma_R^{t+2}X - \theta_R k)}{\delta^{t+1}(\sigma_R^{t+1}X - \theta_R(k - \Delta_N k)) - \delta^{t+2}(\sigma_R^{t+2}X - \theta_R k)} = \frac{\sigma_R^t X - \theta_R k - \delta^2\sigma_R^{t+2}X + \delta^2\theta_R k}{\delta\sigma_R^{t+1}X - \delta\theta_R k + \delta\theta_R\Delta_N k - \delta^2\sigma_R^{t+2}X + \delta^2\theta_R k} = \frac{F}{G}$$

Where $\Delta_N > \Delta_R$, $\theta_N \neq \theta_R$, $\sigma_i^t X > \sigma_i^{t+1}X$, $\sigma_N^t X \neq \sigma_R^t X$

In order to simplify the function, the numerator and denominator for both countries' equilibria are assigned letters F and G, i.e.:

F = $\sigma_j^t X - \theta_j k - \delta^2\sigma_j^{t+2}X + \delta^2\theta_j k$ and G = $\delta\sigma_j^{t+1}X - \delta\theta_j k + \delta\theta_j\Delta_i k - \delta^2\sigma_j^{t+2}X + \delta^2\theta_j k$

Where the countries are once again given identifications *i* and *j*.

Taking the first order conditions with respect to the parameters $\sigma_j^t X, \Delta_i k, \theta_j, k$, which are symmetrical for both countries. Thus, the derivations could apply to any two players, *i* and *j*, *i ≠j:*

The first order conditions:

$$\frac{dp_i}{d\sigma_j^t X} = \frac{G\left(1 - \delta^2\sigma_j^2\right) - F(\delta\sigma_j - \delta^2\sigma_j^2)}{G^2} > 0$$

$$\frac{dp_i}{d\Delta_i k} = \frac{-F\theta_j\delta}{G^2} < 0$$

$$\frac{dp_i}{d\theta_j} = \frac{Gk(\delta^2 - 1) - F\delta(\Delta_i k + \delta k - k)}{G^2} < 0$$

$\frac{dp_i}{dk} = \frac{G\left(-\theta_j+\delta^2\theta_j\right)-\mathrm{F}(-\delta\theta_j+\delta^2\theta_j)}{G^2}$ <0

Note that the derivatives are either positive or negative due to the assumption that the countries' NPVs are positive in the equilibrium equations.

**Proposition 3.** *In mixed strategy equilibrium, the changes in parameters of country j affect the willingness of country j and the probabilities of the country i to enter the Arctic as the first-mover. Here, the periodical reduction in expected investment payoff, X, is assumed to incentivise the countries to enter the Arctic offshore sooner rather than later.*

*(i) Reduction in the expected investment payoff,* $\sigma_j^t X$ *: The larger the periodical reduction in the expected investment payoff, X, the faster the countries are expected to enter the Arctic.*

*(ii) The expected technology spillover,* $\Delta_i k$*: The technology spillover reduces the probability of either of the countries entering the Arctic as a first-mover, as it increases the benefit of entering as the second-mover.*

*(iii) The opportunity cost of alternative future investments,* $\theta_j$*: The opportunity cost of alternative future investments will, by assumption, reduce the willingness of the countries to enter the Arctic offshore.*

*(iv) The capital cost,* $k$*: The larger the capital costs are, the less likely are the countries to be willing to enter the Arctic as the first-mover.*

**Explanation of proposition 3.**

(i) Reduction in the expected investment payoff, $\sigma_j^t X$ : The effect of reduction in expected investment payoff of country j increases the country's willingness to enter the Arctic and also increases the country i's  probability of entering the Arctic as the first-mover, as shown by; $\frac{G\left(1-\delta^2\sigma_j^2\right)-F(\delta\sigma_j-\delta^2\sigma_j^2)}{G^2}$ , which is positive for all values.

(ii) The expected technology spillover, $\Delta_i k$: The derivative of the probability, $p_i$ , with respect to the technology spillover, $\Delta_i k$, is always negative: $\frac{-F\theta_j\delta}{G^2}$ , thus the larger the expected spillover from country *i* to country *j*, the more willing is the country *j* to want to enter as the second-mover, thus reducing the probability of country *i* entering the Arctic as the first-mover.

(iii) The opportunity cost of alternative future investments, $\theta_j$: The increase in opportunity cost increases the option value to wait. Therefore, the increase in $\theta_j$ reduces the country *j*'s willingness to enter the Arctic, which accordingly reduces the probability of country *i* becoming a first-mover, as seen from the derivative, $\frac{Gk(\delta^2-1)-F\delta(\Delta_i k+\delta k-k)}{G^2}$, which is negative for all values.

(iv) The capital cost, *k*: The higher the countries' capital costs are, the less likely are they to be willing to enter the Arctic. An increase in the capital cost thus reduces country *j*'s willingness to enter the Arctic, and consequently lowers the probability of country *i* entering the Arctic as the first-mover, illustrated by the derivative that is negative for all possible values, $\frac{G(-\theta_j+\delta^2\theta_j)-\mathrm{F}(-\delta\theta_j+\delta^2\theta_j)}{G^2}$.

# 4 Discussion and Limitations

Using game theory, more precisely a war of attrition game, this paper found that in mixed strategy Nash equilibrium, where two countries, Norway and Russia, are indifferent between entering the Arctic offshore and not entering, they will postpone their entry due to a second-mover advantage caused by a technology spillover. The same effect was found to be caused by the countries' private perception of irreversibility of investment. In addition, the model was extended to study the effects that a potential oil spill and an expected reduction in investment payoff might have on the strategies of the countries.

The probability of an oil spill, and the potential size of it, measured in costs, was found to negatively affect the willingness to start extraction. This probability of an oil spill occurring was assumed to reduce in each period the country had yet to enter the Arctic, which therefore increased the countries' option value to wait. The reduction in expected investment payoff is less intuitive, but an equally important factor. The countries are assumed to want to enter the Arctic offshore as soon as possible, as long as the expected net present value of doing so is positive. In the extension of the model where the expected payoff reduces in every period, the willingness to initiate extraction is increased. The reduction in payoff is assumed to occur for example due to the countries facing a risk of a backstop technology taking over the market or the Arctic oil and gas becoming stranded assets. The intuition behind the reducing expected payoff is thus that the longer the countries wait to commence extraction in the Arctic, the fewer years they are able to produce before the market demand reduces such that the oil and gas extraction no longer is feasible. Consequently, in equilibrium where both countries are indifferent between entering the Arctic or not, the parameters reducing or increasing one country's willingness to enter the Arctic, also, respectively, reduce or increase the probability of the other country entering the Arctic. All the results gained from the model are as expected, and make sense intuitively.

The model in this paper studies only the mixed strategy Nash equilibrium. In this equilibrium, where the countries observe the other country's action and re-evaluate their strategies in every period, the countries become more unpredictable than if they were to have pure strategies. The countries having pure strategy Nash equilibria is also a realistic application to the situation in the Arctic. A country's strategy may be to "always enter" or "never enter", regardless of the other countries' actions. The study of pure equilibria is an interesting alternative for future study of the oil and gas industries in the Arctic.

The model also only considers the situation where the technology spillover moves from the first-mover to the second-mover, but disregards the possibility of a feedback function existing. If the first-mover were to think that by entering the offshore first, it would gain benefits from the technology spillover due to a feedback function as the others follow, it might be more willing to take on the full entry costs initially. I.e. due to increased activity in the offshore, transportation could become easier, technology more affordable, and cooperation possibility larger, therefore also benefiting the first-mover.

Extending even further from this alternative model with a feedback function, a cooperative game between two or more players can be an interesting extension in studying the region from a game theoretic point of view. Cooperation is extremely important in the Arctic, especially in relation to the oil spill prevention and recovery, but also during the E&P activities. Due to the distance to land and other infrastructure, the oil and gas industries need to create a network of infrastructure in the offshore, especially when expanding extraction further out to the Arctic waters, to allow for safer transportation, for example for the helicopters transporting workers to and from the rigs. Therefore, the study of cooperation and how that affects the expansion of the Arctic offshore oil and gas extraction could be a focus of further studies. In all these extension alternatives, the number of players could also be increased, as the model in this paper only studies the dynamics between two countries. By adding more players the effect that the technology spillover has on all of the Arctic players, both countries and companies, could for example be analysed to a greater extent.

As this study has showed, the future of the Arctic extraction depends on various factors and the analysis of how the region may develop can thus become infinitely complex. That is why it is necessary to divide the topic to smaller parts and focus on specific mechanisms, such as the ones studied in this paper. The number of players was restricted to two and only the parameters perceived as the most important ones were chosen in order to create a simple, but effective model. However, some of the parameters of the model can also be very complex in themselves, when analysed further. For example, the environmental considerations were included in the model through the use of the two parameters describing the opportunity cost of alternative future investment options and the risk of the expected investment payoff reducing, i.e. through the risk of reduction in oil and gas demand that the countries are facing.

These parameters have the ability to capture how the environmental considerations of oil and gas companies are evolving, as the world is becoming more aware of the climate change, while, simultaneously, the oil and gas industries outside the OPEC have to move towards more unconventional and challenging extraction methods and regions. Thus, a simple model, like the one in this paper, can contain a lot of information.

Studying the Arctic oil and gas extraction in a time, when the industries are moving further offshore and to deeper waters, is interesting also due to its external validity. Analysing oil producing countries' and companies' strategies in the Arctic might be applicable to some other, challenging offshore regions in the future. However, the global energy market also seems to be at a crossroads where the renewable energy options are becoming more accessible and competitive compared to fossil fuels. Therefore, analysing the dynamics of the Arctic resource extraction, may give us some insight on how the fossil fuel industries are forecasting the future and how the shift in the market is affecting the strategies of the companies. Perhaps the oil companies will for example find the Arctic too costly and the risk of demand reduction too great, and rather make a strategic move to invest in offshore wind where the technological know-how from offshore oil and gas can be used. At the same time, the Arctic has been in the sights of oil companies for decades now, and therefore it might be difficult to give up the hope of developing the fields, even under certain risks.

# 5 Concluding remarks

Whether the Arctic offshore oil and gas deposits are developed in the coming years, and to what extent, will depend on the Arctic countries' private cost and benefit evaluations, which alter together with changes in the global energy market, the environmental considerations, and strategies of other Arctic countries. In this paper, the strategies of Norway and Russia are analysed using a war of attrition game, where both of the countries adopt mixed strategies. The countries adjust their strategies in every period according to their private evaluations of factors affecting their net payoff and according to the other country's actions.

Especially the technology spillover and irreversibility of investment are brought forward as factors that determine the countries' willingness to extract in the Arctic offshore. The expected spillover may cause inertia at first, but after one country has entered the Arctic offshore, reduces the cost barrier of the other countries entering the Arctic. The irreversibility of investment is measured through the countries' private evaluation of opportunity costs of future alternative investments, which is found to affect the willingness to enter the Arctic negatively.  In addition, the probability of an oil spill occurring is found to reduce the willingness to initiate extraction, especially as the probability of an oil spill is assumed to reduce the longer the countries are to wait before initiating Arctic extraction. However, the countries willingness to enter sooner rather than later is increased due to expected investment payoff decreasing in every period.

The Arctic offshore will most likely be in the focus of the media, politics and various organisations in the years to come. There are many people against E&P activities in the Arctic waters, but also many that depend their income on the northern expansion of the petroleum industry. The drastic changes occurring in the Arctic mean that the region is becoming more attractive to different industries, as waterways are opened and resources are more accessible. However, the Arctic also plays an important role in the battle against the climate change and has become a symbol of the changes occurring on our planet due to the rise in temperature. There is also great variety of marine life and vulnerable ecosystems under, - and on the ice, extent of which today's science is still learning about. Therefore, the Arctic offshore is a region with great complexity and contrast. The decision to extract oil and gas in such a challenging region is not an easy one to make, but as the offshore technology is developing, regions such as the Arctic offshore become more attainable for the oil and gas industries.

However, as the oil and gas industries are volatile from before, adding the unpredictable nature of the Arctic waters to the mix, does not make predicting the future of Arctic extraction easy. Nevertheless, studying specific mechanisms and relationships of the Arctic oil and gas industries, gives us insight as to what the determinants of the Arctic future are, and allows us to make more accurate predictions of the optimal E&P strategies.

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